The Journal of Emergency Medicine, Vol. 49, No. 4, pp. 573–587, 2015

0736-4679/$ - see front matter

http://dx.doi.org/10.1016/j.jemermed.2015.03.013

Clinical Review

BLAST INJURIES

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☐ Abstract—Background: Blast injuries in the United States and worldwide are not uncommon. Partially due to the increasing frequency of both domestic and international terrorist bombing attacks, it is prudent for all emergency physicians to be knowledgeable about blasts and the spectrum of associated injuries. Objective: Our aim was to describe blast physiology, types of blast injuries associated with each body system, and manifestations and management of each injury. Discussion: Blast injuries are generally categorized as primary to quaternary injuries. Primary injuries result from the effect of transmitted blast waves on gas-containing structures, secondary injuries result from the impact of airborne debris, tertiary injury results from transposition of the entire body due to blast wind or structural collapse, and quaternary injuries include almost everything else. Different body systems are affected and managed differently. Despite previous dogma, multiple studies now show that tympanic membrane perforation is a poor predictor of other blast injury. Conclusions: Blast events can produce a myriad of injuries affecting any and every body system. All emergency physicians should be familiar with the presentation and management of these injuries. This knowledge may also be incorporated into triage and discharge protocols guiding management of mass casualty events. © 2015 Elsevier Inc.

☐ Keywords—blast; bombing; terrorism; disaster; mass casualty

INTRODUCTION

Perhaps contrary to common perception, blast injuries in the United States are not rare. Seventy percent of disasters causing >20 dead at the scene are secondary to explosions and fires from a variety of causes, and a 20-year retrospective analysis of bombing events by Kapur et al. identified 36,110 bombing incidents, 5931 bomb-related injuries, and 699 bomb-related deaths in the United States during the study period between 1983 and 2002 (1–4).

In addition, the increasing frequency of both domestic and international terrorist bombing attacks in the last few decades has led to blast injuries formerly only experienced in the context of war (5). Conservative estimates from the RAND® Memorial Institute for the Prevention of Terrorism suggest that terrorist explosive events have risen worldwide fourfold from 1999 to 2006, and injuries related to these acts have increased eightfold during the same period of time (6). Compared to military explosions, civilian blasts impact a wide range of humanity whose medical comorbidities can only be expected to impede their ability to withstand and recover from these events (7). These victims frequently suffer from multidimensional injuries involving primary blast injuries, burns, and both blunt and penetrating wounds (8,9). Penetrating wounds are seen more frequently in terrorist civilian bombing attacks than military explosions, largely because of the lack of body armor (7). A recent review of >3000 terrorist blasts victims revealed a mortality rate of 13% on scene, and 30% of those that survive require admission (10). Notable recent blast events include the World Trade Center (New York City, 1993); Argentine-Israel Mutual Association (Buenos

RECEIVED: 22 August 2014; FINAL SUBMISSION RECEIVED: 4 January 2015;
ACCEPTED: 14 March 2015

Aires, Argentina, 1994); Murrah Federal Building (Oklahoma City, 1995); Olympic Park (Atlanta, GA, 1996); the U.S. embassies (Tanzania and Kenya, 1998); Omagh bombing (Northern Ireland, 1998); the September 11 attacks (New York City, Washington, DC, and Shanksville, PA, 2001); Bali (2001 and 2005); Istanbul (2003); Madrid commuter train bombings (2004); Jakarta (2003, 2004, 2009); London Underground bombings (2005), Bangkok (2007), the Boston Marathon (2013), as well as ongoing incidents in the Middle East (Iraq, Afghanistan, Jordan, Saudi Arabia, and Israel) (1,11,12).

Particularly because of the ever-present risk of terrorism in today's society, it is crucial for prehospital providers and emergency physicians to familiarize themselves with the myriad of injuries caused by blasts (12). Blast events can bring about chaos and panic and often overwhelm the capacity of medical facilities, who are generally unaccustomed to caring for multiple trauma patients simultaneously (9). Despite this, victims need to be directed to the appropriate level of care, and life-threatening injuries need to be promptly diagnosed and treated, as early recognition of blast injuries may improve outcomes (13).

DISCUSSION

Blast Physiology

Blasts are created by the instantaneous transformation of solid or liquid matter to its gaseous form, which produces energy in the form of light, sound, heat, and pressure (5,14). When a high-order explosive detonates (defined in section on Types of Explosives), a "blast wave," or significant air pressure elevation is created. The blast wave can travel at a rate as fast as 8000 m/s, and can reach pressures up to 30,000 times atmospheric pressure (11,15–17). The energy of the blast wave dissipates and its pressure decreases as the wave travels. Blast wind, which follows the blast wave, consists of powerful, fast-moving, superheated air that can lift bodies and destroy structures, which can result in both blunt and penetrating injuries (6,7,11).

The blast wave leads to injury through spalling, implosion, and inertia. Spalling is "displacement and fragmentation of the denser into the less dense medium." Alveolar hemorrhage is an example effect of spalling in the lung. Implosion is "displacement of the less dense into the denser medium." Air emboli traveling into the pulmonary circulation is an example effect of implosion in the lung (7,18). The definition of inertia is "shear stress created by the blast wave traveling through tissues of different densities at different velocities." In the abdomen, for instance, this can cause tissue tearing secondary to disparate movement of the abdominal wall and viscera (11,16,18).

Types of Explosives

Explosives are either high-order explosives that create supersonic blasts or low-order explosives that create subsonic blasts with less sheer velocity (12). High-order explosives include C-4, Semtex, trinitrotoluene (TNT), gelignite, dynamite, nitroglycerin, and ammonium nitrate fuel oil; and low-order explosives include gunpowder, pipe bombs, as well as Molotov cocktails and most other petroleum-based bombs (11,12,19). Low-order explosives are generally utilized as propellants and pyrotechnics. Propellants are devised to produce a controlled release of energy, and pyrotechnics are devised to create light, smoke, heat, and sound (20). While homemade bombs are often low-order explosives, this is not always the case, as rogue states and large-scale networks that sponsor terrorism can provide militants with the necessary supplies for the creation of high-order explosives; additionally, ammonium nitrate, which is used in the creation of some high-order explosives, can be easily amassed in the form of crop fertilizers (12).

The damage caused by explosives can be compounded by the addition of hazardous shrapnel (such as nails, screws, or ball bearings) or infectious agents, such as hepatitis B or C from blood debris (21,22). Additionally, evolving technology has allowed improvised explosive devices (IEDs) to be triggered remotely via cell phones and with complex timing for the initiation of multiple blasts (23).

"Dirty bombs" can exponentially increase blast-related destruction through the addition of nuclear materials or chemical agents that are dispersed when the bomb goes off (12,24). Newer thermobaric (or enhanced-blast) weapons emit gas before exploding, which leads to a larger pressure wave that has the ability to extend around corners and cause a much greater path of destruction than with conventional explosives (7).

CLASSIFICATION OF BLAST INJURIES

Primary Blast Injury

Blast injury is typically classified as primary to quaternary, occasionally as primary to quinternary/quinary. Blast waves themselves cause primary blast injuries (PBIs) and generally affect gas-containing organs, most commonly the eardrums and lungs and, to a lesser extent, bowel (25). As mentioned already, PBI develops when a blast wave accelerates and decelerates while traveling through tissues of varying density (11).

Unlike other forms of blast injury, body armor cannot protect against PBI (11,26). Examples of PBIs include blast lung, "hemothorax, pneumothorax, tension pneumothorax, acute arterial gas embolism,